Abstract

Adaptive Sampling Pattern Design Methods for MR Images

MRI is a very useful imaging modality in medical imaging for both diagnostic as well as functional studies. It provides excellent soft tissue contrast in several diagnostic studies. It is widely used to study the functional aspects of brain and to study the diffusion of water molecules across tissues. Image acquisition in MR is slow due to longer data acquisition time, gradient ramp-up and stabilization delays. Repetitive scans are also needed to overcome any artefacts due to patient motion, field inhomogeneity and to improve signal to noise ratio (SNR). Scanning becomes difficult in case of claustrophobic patients, and in younger/older patients who are unable to cooperate and prone to uncontrollable motions inside the scanner. New MR procedures, advanced research in neuro and functional imaging are demanding better resolutions and scan speeds which implies there is need to acquire more data in a shorter time frame. The hardware approach to faster k-space scanning methods involves efficient pulse sequence and gradient waveform design methods. Such methods have reached a physical and physiological limit. Alternately, methods have been proposed to reduce the scan time by undersampling the k-space data. Since the advent of Compressive Sensing (CS), there has been a tremendous interest in developing undersampling matrices for MRI. Mathematical assumptions on the probability distribution function (pdf) of k-space have led researchers to come up with efficient undersampling matrices for sampling MR k-space data. The recent approaches adaptively sample the k-space, based on the k-space of reference image as the probability distribution instead of a mathematical distribution, to come with an efficient undersampling scheme. In general, the methods use a deterministic central circular/square region and probabilistic sampling of the rest of the k-space. In these methods, the sampling distribution may not follow the selected pdf and

the selection of deterministic and probabilistic sampling distribution parameters are heuristic in nature.

Two novel adaptive Variable Density Sampling (VDS) methods are proposed to address the heuristic nature of the sampling k-space such that the selected pdf matches the k-space energy distribution of a given fully sampled reference k-space or the MR image. The proposed methods use a novel approach of binning the pdf derived from the fully sampled k-space energy distribution of a reference image. The normalized k-space magnitude spectrum of the reference image is taken as a 2D probability distribution function which is divided in to number of exponentially weighted magnitude bins obtained from the corresponding histogram of the k-space magnitude spectrum.

In the first method, the normalized k-space histogram is binned exponentially, and the resulting exponentially binned 2D pdf is used with a suitable control parameter to obtain a sampling pattern of desired undersampling ratio. The resulting sampling pattern is an adaptive VDS pattern mimicking the energy distribution of the original k-space.

In the second method, the binning of the magnitude spectrum of k-space is followed by ranking of the bins by its spectral energy content. A cost function is defined to evaluate the k-space energy being captured by the bin. The samples are selected from the energy rank ordered bins using a Knapsack constraint. The energy ranking and the Knapsack criterion result in the selection of sampling points from the highly relevant bins and gives a very robust sampling grid with well defined sparsity level.

Finally, the feasibility of developing a single adaptive VDS sampling pattern for a organ specific or multislice MR imaging, using the concept of binning of magnitude spectrum of the k-space, is investigated. Based on the premise that k-space of different organs have a different energy distribution structure to one another, the MR images of organs can be classified based on their spectral content and develop a single adaptive VDS sampling pattern for imaging an organ or multiple slices of the same. The classification is done using the k-space bin histogram as feature vectors and k-means clustering. Based on the nearest distance to the centroid of the organ cluster, a template image is selected to generate the sampling grid for the organ under consideration.

Using the state of the art MR reconstruction algorithms, the performance of the proposed novel adaptive Variable Density Sampling (VDS) methods using image quality measures is evaluated and compared with other VDS methods. The reconstructions show significant improvement in image quality parameters quantitavely and visual reduction in artefacts at 20% 15%, 10% and 5% undersampling.